5. Reanalysis Evaluation
Objective: Identify the various requirements for reanalysis products.

Session Chair: Jim Carton, U. of Maryland
Rapporteur: Steve Penny, U. of Maryland

**1:30 p.m. Dry-mass conservation and water consistency in reanalysis
Ricardo Todling, NASA/GMAO**

Presented: An approach to conserve dry mass in reanalyses.
Summary: Three modifications made to the model, analysis, and increments.

Definition: Total mass (in this work) is the sum of atmospheric dry mass and the mass of total water content.
Evaluation in Pre-MERRA-2
Still see impacts by changes in observing system.
Addressing this to first order by conserving dry mass in the reanalysis.
See E&P out of balance in all of: MERRA/ERA-Int/JRA-55/NCEP-CFSR
Precipitation changed more than evaporation due to changes in observing system.
The dry mass is changing more in conjunction with the total mass. (not what is desired).
3 Changes, to the MODEL, ANALYSIS, and INCREMENT:
(1) Changes in total mass totally determined by how model handles moist physics. {MODEL}
(2) Constraint to analysis system to better preserve dry mass (no increment in total dry mass) {ANALYSIS}
(3) Adjustment to surface pressure and water tendencies of IAU {INCREMENT}

AMIP Experiment
Change in dry mass is consistent with change in total mass.

Two test experiments: March 2003, March 2009 (where there was a jump in the GMAO RPIT Reanalysis)
(1) ADAS-1: modifies AGCM & GSI but leaves IAU untouched
(2) ADAS-2: All changes applied to ADAS (all 3 modifications)

In pre-merra-2:
total and dry mass track together and wet mass is doing its own thing.
ADAS-1, with adjustment:

There is more correlation in total and wet mass (but dry mass not quite conserved)
ADAS-2 (in an IAU-based system, you need more):
The dry mass is now fully conserved and all changes in total mass are fully driven by what is happening in the moist component

Preliminary results in MERRA-2 show a conservation in dry-mass
Evaporation for merra-2 is relatively more stable over time than with merra-1.
Total precipitable water compared to GSSTF is improved in merra-2 vs. merra-1.
Some of the big jumps have been eliminated.

Gil: what is the physical mechanism by changing integrated dry mass to be constant; why did this make precipitation better?
R: The dynamics conserve mass, so that only thing that should change or control the water is the physics, but if you allow
the assimilation to adjust it then it can get out of balance.
The increments are just scaled by a single number (e.g. 0.9999 or 0.0001)
Dick: Do you have a clean experiment that shows these improvements?
R: the details behind these experiments are clean (same model) and shown in a larger document
Arun:
R: now the model is actually less biased than before.

1:50 pm Air-sea heat and freshwater fluxes in Atmospheric Reanalyses
Lisan Yu, Woods Hole Oceanographic Institute

<u>Presented</u>: An analysis of energy and freshwater budgets over the global ocean based on surface fluxes from many reanalysis products with validation to in situ buoys.
<u>Summary</u>: Most uncertainty is concentrated in the tropics, and the spread in heat fluxes are primarily seen in the SW fluxes.

Products: used all available reanalysis products. Satellite analyses (OAFlux), Ocean reanalysis (MIT ECCO4, 1992-)
All of the spread amongst the products is in the tropics, especially the ITCZ region.
Showed energy and freshwater budgets over the global ice-free ocean.
What causes the global imbalances in the products?
Uncertainty in the air-sea heat fluxes are largest in the Short Wave.
In the tropics, the spread in SW is about twice as high as the spread in LH+SH+LW.
Solar radiation: SW is largest in the tropics out of all products.

Qnet into the ocean is lowest in the JRA-55
Solar radiation defines the seasonal cycle.
More months of Qnet gain than months of Qnet loss.
Northern hemisphere is more spread in summer than southern hemisphere.
Buoy validation:
NCEP1, NCEP2, CFSR, broad distribution (0.5 correlation coef.) and 33 W/m^2 bias
MERRA and ERA-INT relatively good
CFSR significantly overestimates SW in tropics.
LH, excessive cooling in NCEP2 and ERA-Int

In the equator: JRA-55, large heat flux, and large precipitation, to keep mass conserved
Unlike Qnet, the E-P products do not agree on the seasonal cycle.
Seasonal cycle of salinity should reflect the seasonal cycle of E-P.

Jumps in E-P errors:
MERRA and CFSR due to precipitation

No consensus amongst analyzed products in linear trends of Qnet.

All Qnet products show downward trend when ocean heat content increases.
JRA-55 is an outlier.
CFSR a better product for front-scale air-sea interactions, but the long time series is not reliable.

Santha: as buoys are measuring the SW, the measurements are at different heights. How to account for differences temporally, and instruments at different heights?
L: Daily data as a basic guide. Compute 0-24 average. Use two sets of buoys, measured at same level. One TOGA. Regard buoys as 2.3-2.5 and at same level.
Most change not due to height but due to incident angle (due to waves).
Xingren: the CFSR has hourly output, each hour is a cumulative measure up to the forecast hour, and hourly output should not be averaged to get daily data.

2:10 p.m. Impacts of NCEP Reanalysis R2 and CFSR fluxes on MOM4 simulations
Caihong Wen, NCEP/CPC

Presented: Various surface fluxes from the R2 were replaced with surface fluxes from the CFSR to identify which surface uncertainties had the largest impact on the ocean uncertainty.

Summary: Heat Flux -> SST, wind stress -> D20, E-P -> SSS.

How do uncertainties in surface fluxes contribute to the uncertainty in the background state used by GODAS?
Goal to identify uncertainty between NCEP R2 and CFSR (1986-2013)
Significant differences between the R2 and the CFSR occur in the tropics.
Daily surface fluxes (E-P, tau, net heat flux) applied to MOM4p1. Relaxed to daily OISST and monthly climatology SSS.
experiments with different combinations of R2 and CFSR forcing fields were applied.

For evaluation, focused on climatological mean bias.
Uncertainty in SST due to uncertainty in net heat flux.
Uncertainty in surface wind is an important factor in identifying the D20
Uncertainty in surface net heat fluxes has strong impact on temperature mean in the upper ocean (150m)
Subsurface temperature anomalies near thermocline in the indian -western pacific are sensitive to surface wind forcing.
Uncertainty of E-P is the primary factor contributing to SSS differences between R2 forcing and CFSR forcing runs. Especially near the equator and southern tropical oceans.

Differences mainly occur in tropical regions, where there is clear difference between the surface fluxes.

2:30 p.m. Evaluation and intercomparison of clouds, precipitation, and radiation budgets in recent reanalyses using satellite-surface observations Erica Dolinar, U. of North Dakota

Presented: A comparison of cloud fraction (CF), precipitation rate (PR), net cloud radiative effect (CRE) from 5 different reanalyses.
Summary: In some cases, large biases in CF, PR and CRE are present in the reanalyses, but the fields are physically consistent.

using 5 reanalyzes: 20CR, CFSR, ERA-Int, JRA-25 and MERRA.
evaluated with CERES/MODIS, ARM

Task 1: 45ºS-45ºN, 2000-2012
High cloud fraction (CF) in s. ocean n. pacific and Atlantic, and the ITCZ
Overprediction in CFSR and 20CR
All reanalyses underpredict CF
Precipitation rate (PR)
Issues with diurnal cycle, orographic precipitation initiation

Reanalysis all overpredict PR

Net cloud radiative effect (CRE)
In general, all over predict the net CRE

Task 2: biases in two dynamic regimes
vertical motion at 500 hPa
strong ascent leading to deep convection in the tropics
moderate to strong subsidence creates an environment favorable for low-level
MBL stratocumulus clouds.
how are CF, PR and CRE predicted in the two regimes?
Ascent regime (convective-type clouds)
over predicted by 4-14%, CFSR -7.7%
Descent:
underpredicted

Higher PRs in acsent than descent -> different cloud types in the two regimes.
ascent - normal distribution, descent - distribution is skewed

ascent TOA fluxes and CREs
large all-sky SWUP negative bias in CFSR, gives weaker CRE.
MERRA has positive bias in all-sky SWUP gives stronger CRE.
Radiative fluxes are consistent with CF results.

Descent - opposite to ascent regime. SWUP and OLR positively biased in CFSR,
stronger SW CRE. SWUP small negative bias -> weaker SW CRE.
Calculated SWUP in CFSR not consistent with CF. MERRA pretty consistent.

Task 3: comparison with two ground-based ARM sites
Azores, Nauru Island
Azores (eastern north atlantic)
Observed CF 70%, all reanalyses underpredict.
Observed SWDN ~162W/m^2. All reanalyses except MERRA overpredict.
Observed SW
Observed LWDN ~358 W/m^2, reanalyses underpredict.
Yet, all were physically consistent.

Nauru Island:
CF, all over predict, except CFSR
SWDN all under predict except CFSR and MERRA
SW, all under predict except CFSR and MERRA
LWDN, various results
All results are physically consistent.

Still have issues parameterizing convective and MBL clouds as well as their impact on radiation budget.
Advancement in convective-type cloud parameterization slow.

2:50 p.m. Coffee Break

3:10 p.m. Investigation of two extreme summer Arctic sea-ice extent anomalies in 2007 and 1996
Xiquan Dong, U. of North Dakota

Presented: A comparison of three different historical periods experiencing extreme conditions vs. historical average (1996, 2007, 2012), and their dynamical features.
Conclusion: Extremes triggered by anomalous synoptic patterns.

The summer of 2007 september sea-ice extent hit a record minimum (35% below 1979-2007 average)
Focused on area of Laptev, East Siberian and Chukchi seas and define it as the area of focus.
The variables during the summer 1996 are opposite to those in 2007.
2007: anti-cyclone system. Southerly wind, warm positive anomaly.
1996: cyclonic wind, cold air.
2007: CF over AOF is 7% higher than climate mean, net LW flux is +10 W/m^2, net SW is -4.2 W/m^2.
Total net surface energy is +7 W/m^2.
1996 reverse.
Summer 2007: all positive anomalies except SW.

2012, new record low, mainly triggered by superstorm over the central arctic ocean.
Significantly different synoptic pattern from those in 2007.
The patterns and anomalies are the same as 2007, but the magnitudes are much smaller.

Low sea ice extent (SIE) in 2007 was associated with a persistent anticyclone over the before sea coupled with low pressure over aquaria.

SIE in 1996: associated with persistent low pressure over the central arctic.

part 2: cloud radiation PWV feedback on 2007 low SIE

during spring months of 2007 -> strong southerly winds brought more warm and

moist air over the AOF
CF, LW and SW were below their climatological values because most of the arctic ocean surfaces were still covered by sea ice during spring.

meridional winds, water vapor, cloud and radiation having significant impact on SIC variations.

Summary 2:
onset of 2007 low sea-ice extent was triggered by the large-scale atmospheric circulation anomaly during the spring months of 2007
strong southerly winds brought warm and moist air from the north pacific
downwelling LW flux increased with increased PWV

progress by UND group:
arctic clouds and radiative forcing
assessment of reanalyzed arctic clouds and radiative forcing using satellite observations. compared to observed CF, all reanalyzed CFs are much higher during winter in the arctic.
comparison of GPCP precipitation with Q2 precipitation over the CONUS
annual mean difference is small, but regional differences can be large. (GPCP vs. Q2)

Gil: Be careful about 'correlation implies causation' argument in (p.14) analysis.
Jim C.:
X: Increase in clouds led to increase in net LW down into the ocean. LW effect is dominant due to the high angle of incidence of SW and the persistent presence of the downward LW.

3:30 p.m. Reanalysis evaluation in polar regions
Richard Cullather, NASA/GMAO

<u>Presented</u>: Updates on reanalysis of sea-ice and land-ice ice in the polar regions, including comparison between regional and global models for reanalysis over polar ice sheets.
<u>Summary</u>: Sea and land ice data assimilation are still in early phases, climatological forcings are difficult to beat but reanalysis may be informed by higher resolution regional model reanalysis studies.

Reanalyses in high latitudes are useful because they combine available, sparse data sources into a coherent picture.
The provide initial and boundary conditions for seasonal prediction of sea ice and land ice modeling

Reanalyses are a variety of issues related to high-latitude physical parameterizations:
-uncertain boundary conditions
-spatial resolution
-surface hydrology and radiative processes (albedo)
-multiple-phase clouds
Reanalyses as ICs for seasonal sea-ice forecasts:
ocean models spun up with merra reanalyses
10^0 temperature bias in month of May due to using MERRA for
MERRA-2: use tower albedos from field study and produce seasonal climatology of surface albedo.
Use CICEthermo (separate dynamic and thermodynamic components)
Climatology difficult to beat since the climatological cycle is so strong.
Main issues are from the surface of the ice downward (into the ocean).
Sea-ice concentration from 7 reanalyses results in a relatively small spread.
17 ocean reanalyses have very large arctic sea ice volume spread. a main predictor in sea-ice extent forecasts
sea ice thickness can be deduced from satellite, but that must be spread out into different categories, and that is so far 'black magic'.
airborne ice altimetry has a very fine spatial resolution, and that can be used to work out ice categorizations to some degree.
Putting in ice thickness can create gravity waves. and if the ocean is too warm, then a stand-alone ice analysis will result in the ice just melting away. you need a coupled ice analysis to prevent this.

Reanalyses over polar ice sheets:
used to evaluate changing surface conditions.
Gtopo30 was important, but now its over and we need to move on to new topographic datasets.

Greenland surface mass balance:
big differences between several reanalyses

runoff:
also big differences between reanalyses.

Regional climate models have become widely used over the polar ice sheets. They tend to have much greater melt.
able to incorporate locally-specific model physical parameterizations including snow hydrology, and firn processes, prognostic surface albedo.
MERRA: snow on ice sheet is antimatter.

Use of RCMs can also incur risk:

Interactive downscaling over the polar ice sheets:
dynamical ice sheet models (ISMs), higher resolution than GCM, simulate the flow of ice, leading to iceberg calving
Operate on very-high res meshes.

if you have a field at a certain res, the corresponding field (interpolation and downscaling), then use that to force the ice.
limits: topographic blocking. it's better if the GCM is higher resolution.

reanalyses are vital, but face challenges due to unique physical processes (e.g. clouds not described in detail here), data scarcity, and complex surface conditions.
initial conditions for models are known to be disparate.
incorporation of sea ice thickness into models is not trivial.

downscaling over polar ice sheet:
we only have information at specific locations, so the downscaling allows us to map the low resolution information to these locations.
regional models show much higher mass balance in the southeast (of greenland), an area not well observed.

3:50 p.m. Rapporteurs give 5 minute summary of their session

4:15 p.m. Discussion and writing assignments